AD-A252 326

PL-TR-92-2099

(2)

MAGNETOSPHERIC STRUCTURE AND DYNAMICS:
A MULTISATELLITE APPROACH

W. JEFFREY HUGHES

Boston University
Center for Space Physics
725 Commonwealth Avenue
Boston, MA 02215

9 April 1992

Scientific Report No. 2

Approved for public release; distribution unlimited

Phillips Laboratory
Air Force Systems Command
Hanscom Air Force Base, Massachusetts 01731-5000

This technical report has been reviewed and is approved for publication.

IRVING MICHAEL
Contract Manager
Space Plasmas and Fields Branch
Space Physics Division

NELSON C. MAYNARD, Chief
Space Plasmas and Fields Branch
Space Physics Division

WILLIAM SWIDER
Deputy Director
Space Physics Division

This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify PL/TSI, Hanscom AFB, MA 01731-5000. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document require that it be returned.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	9 April 1992	Scientific No. 2

4. TITLE AND SUBTITLE
Magnetospheric Structure and Dynamics:
A Multisatellite Approach

5. FUNDING NUMBERS
PE 61102F
PR 7601 TA 18 WU JA

Contract F19628-90-K-0003

6. AUTHOR(S)
W. Jeffrey Hughes

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Boston University
Center for Space Physics
725 Commonwealth Avenue
Boston, MA 02215

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Phillips Laboratory
Hanscom AFB, MA 01731-5000

Contract Manager: Irving Michael/GPSG

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
PL-TR-92-2099

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
Distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report focuses on four areas of scientific investigation in which significant progress has been made during the second year of the contract: electrostatic electron cyclotron harmonic emissions observed by CRRES; the implications of cross tail plasma gradients on the structure of auroral zone; ULF waves excited by storm sudden commencements; and probing flux tube plasma content and distribution using the observed frequencies of field line resonances. Each of these topics is made the subject of one section of this report and has or will result in publication of a scientific paper. Here we summarize the main scientific results and refer the reader to one or more of the publications arising out of our research for fuller details. A complete list of publications arising out of this research is contained in the last section of this report.

14. SUBJECT TERMS
Magnetosphere, plasma waves, ULF waves, hydromagnetic waves, field aligned currents, aurora.

15. NUMBER OF PAGES
14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

I. Introduction

This contract funds a comprehensive five year study of magnetospheric structure and dynamics. There are four major areas of study: waves and wave particle interactions, magnetospheric tail and substorm dynamics, ionosphere-magnetosphere coupling, and active experiments. The first three areas are all central to our understanding of the geoplasma environment. Each plays a critical part in determining the pattern of plasma flows and currents and the distribution and properties of the plasma and energetic particles within the magnetosphere-ionosphere system. The last topic, active experiments, is an exciting emerging field in space plasmas that holds much potential. The major effort is directed towards the analysis of existing and newly acquired spacecraft data, with particular emphasis on multi-satellite studies. The data analysis is complemented with theoretical and simulation studies, the development and maintenance of data analysis and display software for use in the data analysis, and the design of new innovative plasma and field instruments for use in the next generation of spacecraft. The overall goal of the study is to provide the understanding of the magnetosphere-ionosphere system needed to construct reliable models that will forecast the future state of the system.

This report focuses on four areas of scientific investigation in which significant progress has been made during the second year of the contract: electrostatic electron cyclotron harmonic emissions observed by CRRES; the implications of cross tail plasma gradients on the structure of the auroral zone; ULF waves excited by storm sudden commencements; and probing flux tube plasma content and distribution using the observed frequencies of field line resonances. Each of these topics is made the subject of one section of this report and has or will result in the publication of a scientific paper. Here we summarize the main scientific results and refer the reader to one or more of the publications arising out of our research for fuller details. A complete list of publications arising out of this research is contained in the last section of this report.

II. Banded Electrostatic Emissions Observed by CRRES

Our first detailed study with the CRRES plasma wave data focused on the banded electrostatic emissions that occur between the electron cyclotron frequency and the plasma frequency in bands between multiples of the cyclotron frequency. These waves, sometimes referred to as the $n + \frac{1}{2}$ emissions, are observed, except for rare occasions, whenever CRRES is outside the plasmasphere. They are the result of the warm electron population (10 - 100 eV) convected from the tail that is unstable in the presence of cold electrons. These waves were studied extensively in the past when it was thought that they were responsible for the electron precipitation that caused the diffuse aurora. It now appears that these waves have insufficient power to precipitate the electrons, but in the absence of any other viable mechanism, the possibility remains that these waves are somehow responsible. The CRRES wave instrument is able to add much more detailed information on the frequency spectra of these waves, so that is what our study concentrated on. Exactly what part of frequency space the most intense waves are seen can help decide on the exact generation mechanism, and throw further light on whether these waves can cause significant particle precipitation.

The global features of the electron cyclotron harmonic (ECH) emissions detected by CRRES show good agreement with previous studies. Event duration, occurrence frequency and emission intensity are consistent with past observations for the local times studied (2230 - 0730 MLT, the range of local time CRRES covered during the early part of its mission). The most intense emissions are confined to within 3° or 4° of the magnetic equator. Strong equatorial emissions were observed every time CRRES crossed the equator outside the plasmasphere. Off the equator much lower intensity emissions were observed on 95% of all orbits, and for the remaining orbits probably CRRES remained within the plasmasphere for the whole orbit. A detailed examination of the high time resolution spectrum analyser data for two specific intervals showed that the waves were strongly polarised perpendicular to the magnetic field. When both near and off equator ECH emissions are seen on the same orbit, the same relative frequencies (i.e. frequencies normalised to the electron cyclotron frequency) are excited both on and off the equator. The difference between near and off equator emissions is that within a few degrees of the equator a subset of the excited frequencies have much larger spectral densities that the others. A study of bandwidth reflected this. Near equator emissions have narrow bandwidths (usually less than 0.1 f_{ce}), while off the equator the bandwidths are much broader, comparible to f_{ce}.

A statistical study of the normalised emission frequency ($\mu = f/f_{ce}$) for a large number of ECH events showed which frequencies are most amplified. Near the equator ECH emissions are almost exclusively in the upper half of each cyclotron harmonic interval, i.e. intense emissions are seen at $\mu = n + x$; $0.5 < x < 1$, and the most intense emissions are at frequencies very near the top of each interval. There are two exceptions, both in the lowest frequency harmonic interval (i.e. $1 < \mu < 2$), in regions of higher electron number density and near midnight.

Comparing our results to earlier work, we find, based on bandwidth, intensity and prox-

imity to the magnetic equator, that convective growth and amplification at certain frequencies are not fully addresed by Hubbard and Birmingham's [1978] plasma model and classification of the these waves. Using the calculations of Ashour-Abdalla [1979] and the plasma parameters from the CRRES data, we found that the emissions we detect are likely to be convective for a wide range of n_c/n_h. Barbosa's [1985] model is appropriate for addressing the aspects of the observed spectrum not discussed by Hubbard and Birmingham. However Barbosa's model predicts greatest amplification at a different part of the spectrum from where we observe the highest intensity waves. Since this model addresses what are probably the remaining issues in understanding the ECH spectrum, further calculations are needed using parameters appropriate to this region of the magnetosphre, and tracing the ray paths of emissions just below multiples of the electron cyclotron harmonics.

Principal Reference

Paranicas C., W.J. Hughes, H.J. Singer, and R.R. Anderson. Banded electrostatic emissions observed by the CRRES plasma wave experiment, submitted to *J. Geophys. Res.*

Other References

Ashour-Abdalla, M., C.F. Kennel and W. Livesey, A parametric study of electron multiharmonic instabilities in the magnetosphere, *J. Geophys. Res.*, *84*, 6540, 1979.

Barbosa, D.D., Electrostatic Wave Propagation and trapping near the magnetic equator, *Ann. Geophys.*, *3*, 63, 1985.

Hubbard, R.F., and T.J. Birmingham, Electrostatic emissions between electron gyroharmonics in the outer magnetosphere, *J. Geophys. Res.*, *83*, 4837, 1978.

III. Consequences of Dawnside Depletion on Auroral Structure

The westward gradient and curvature drift of energetic ions in the tail results in a depletion of plasma on convecting flux tubes on the dawn side of the tail. The resulting cross-tail gradients in plasma pressure generate field aligned currents. Many of the routinely observed features of the auroral zone electric field, field aligned current and precipitation patterns in the earth's ionosphere can be understood as a consequence of these pressure gradients and currents. The currents flow out of the ionosphere in the middle of the nightside auroral zone resulting in a reversal of the meridional component of the electric field known as the Harang discontinuity [Erickson et al., 1991; Liu and Rostoker, 1991]. The field aligned currents feed into the cross tail current so that it is more intense on the dusk side than on the dawn side of the plasma sheet. This effects the symmetery of the entire magnetospheric current system, in particular it leads to an asymmetry in the region-1 currents that map to the nightside boundary layer. The additional duskside cross-tail current must close within the magnetospheric current system. From an analysis of the global mapping of observed field aligned current intensities we conclude that closure, at least in part, via downward region-1 current on the dawn side of the tail is consistent with the observations.

A more detailed study of the characteristics of the sources of field aligned current on the nightside suggests that the currents produced by the dawnside depletion effect separate the auroral zone into two regions in addition to the regions of field aligned currents that map to the magnetospheric boundary layer (region-1) and those that map to the inner edge of the plasma sheet (region-2). In the plasma sheet the regions are distinguished by the relative alignment of convection flow lines and contours of constant flux tube content. In the first region these two sets of curves are approximately orthogonal to each other. This results in a region of relatively uniform field aligned current generation. In the second region the two sets of curves are roughly parallel. As the relative orientation of these lines controls whether the field aligned current flows into or out of the ionosphere, small variations in either the electric field pattern (brought about by, say, variations in ionospheric conductivity), or in flux tube content (brought about by differing histories of neighboring flux tubes and time variations in the solar wind and IMF), will cause significant differences in the local field aligned current.

At low altitudes the first region includes the Harang discontinuity and the main auroral zone poleward and eastward of the Harang discontinuity (but equatorward of the boundary layer). This region is characterised by upward field aligned current and the associated acceleration and precipitation of electrons, which is relatively free of small scale structure. At its equatorward boundary this region merges smoothly with the region of upward region-2 currents on the dawnside of the Harang discontinuity. The other region is westward and equatorward of the Harang discontinuity and contains the main premidnight and duskside auroral zone between the downward region-2 currents and the boundary layer. This region also has a net upward current. However in contrast to the other region, this region is sensitive to small perturbations in the plasma sheet populations; small scale structures in plasma sheet flux tube content produce complex patterns of alternating regions of upward and downward

current. So at low altitudes this region is characterised by complex small scale structures such as small scale arcs and inverted-V's.

We have completed an initial study of low altitude data from DE-2 and DMSP to see if this structure is apparent. The data shows that these different regions can be distinguished in the field and particle data. In the evening and midnight sectors relatively uniform particle distributions are seen poleward of the electric field reversal, but equatorward of this boundary, the electron spectra and field patterns show much more structure. The inner part of the plasma sheet is a critical region for the onset of substorms. The implications of this dawn/dusk asymmetry in the inner plasma sheet on location and timing of substorm initiation is the subject of our next inquiry.

Principal References

Erickson, G.M., The physics of the Harang discontinuity, 2. Consequences of dawnside depletion, *J. Geophys. Res.* (in press), 1992.

Other References

Erickson, G.M., R.W. Spiro, and R.A. Wolf, The physics of the Harang discontinuity. *J. Geophys. Res., 96,* 1467, 1991.

Liu, W.W., and G. Rostoker, Effects of dawn-dusk pressure asymmetry on convection in the central plasma sheet, *J. Geophys. Res., 96,* 11501, 1991.

IV. ULF Waves Excited by Storm Sudden Commencements.

One of the difficulties with studying ULF waves is that often the exact source of energy that excited the wave is not clear. Such is not the case for those waves that immediately follow a storm sudden commencement (SSC) as these waves are generated as a result of the sudden deformation of the magnetosphere brought about by an interplanary shock. These waves provide an opportunity to study how a broad band impulse such as an SSC is converted into relatively narrow band waves. A crucial question is whether fast mode resonances of the entire magnetospheric cavity (cavity modes) play an intermediate role in feeding energy into the field line resonant oscillations observed. We began our study of SSC-excited ULF waves using CRRES data with a case study, choosing the waves seen immediately after the SSC that preceded the geomagnetic storm of 26 August 1991. This case study will be followed by a statisical study of the waves observed following the approximately 50 SSC's that occured during the CRRES mission.

ULF waves were observed for the whole 90 minute interval between the SSC at 0535 UT on August 26, and the main phase of the storm that followed. The waves clearly break into three segments each of about 30 min. During each of these segments the wave frequencies are relatively constant, but the frequencies change between intervals. The first interval consists of toroidal waves. These seem to be directly driven by the SSC shock wave passing over the magnetopause, as we could find no evidence of cavity waves. During this interval two sets of field line resonant harmonics are apparent as families of peaks in the wave spectra, one set more intense than the other. We conclude that discrete field line resonant harmonics were excited on two flux tubes that had different eigenfrequencies, both in the vicinity of CRRES, and that the satellite was near enough to both flux tubes to sense both sets of harmonic frequencies. A second interval of harmonic waves with a slightly different set of frequencies was observed during the next half hour. In contrast to the first set, these were accompanied by compressional oscillations. These could either be the result of a cavity oscillation, or be waves internally generated by a mirror or similar instability of the trapped energetic particle population that was was made unstable by being compressed by the SSC. However the frequency of the compressional waves is consistent with the theorically computed frequency of the cavity mode, which adds credence to that explanation.

The most interesting result from this case study is the simultaneous observation of two sets of harmonics, which poses the question of what determines which flux tubes can support field line resonances. Cavity modes provide a simple explanation of this, as only those flux tubes that have eigenfrequencies that match the cavity mode eigenfrequencies will be excited. But in this case there was no evidence of a cavity mode. Our next task is to see whether this example is typical of the many examples of SSC-excited ULF waves in the CRRES data.

Principal Reference

Ludlow, G.R., W.J. Hughes and H.J. Singer, CRRES Observations of SSC Excited ULF Waves 1: Case Study, to be submitted to *J. Geophys. Res.*

V. Probing Plasma Structure Using Field Line Resonances.

Shear mode Alfven waves propagate strictly along magnetic field lines. On the dayside of the earth, the highly conducting ionospheres at either end of a field line act as excellent reflectors of shear mode Alfven waves, with the result that a field line becomes a 1-dimensional resonant cavity that can support waves at a family of resonant frequencies. There is presumably sufficient broad band noise in the magnetosphere to continually excite these harmonic resonances as it is not unusual for a spacecraft to see a field line resonating at several of its resonant harmonics. CRRES regularly observes multiple harmonics of resonant field line oscillations, especially on the dayside. These appear on orbit time-frequency spectrograms made from the flux gate magnetometer data as characteristic families of dish shaped curves. This is the result of the harmonic frequencies decreasing during the first half of the orbit as CRRES moves to longer field lines with lower resonant frequencies until it reaches apogee and then increasing as CRRES moves back across increasingly shorter field lines.

The frequencies of resonant hydromagnetic oscillations of a field line are sensitive to the distribution of plasma mass density along the entire flux tube. Using a model in which plasma mass density, ρ, was distributed along the field line as $\rho = \rho_0(r_0/r)^m$ where r is the geocentric distance to a point on the field line, Cummings et al. [1969] calculated how the eigenfrequencies depend on the mass distribution. We have shown that it is possible to use their calculations and the values of the resonant frequencies observed by CRRES to deduce the equatorial mass density, ρ_0, and the mass distribution index, m, of the flux tubes CRRES *crosses on its orbit.* By combining this result with the total electron number density deduced from the upper hybrid frequency observed by the plasma wave instrument. we can also obtain the mean ion mass for that field line, and hence obtain an indication of the ionic composition of the plasma.

We have tried this technique on about 6 orbits from both the local morning and evening sectors. In general the index m is well determined with an uncertainty of about ± 1. We found that values of the index m vary from 1 or 0, indicating a near constant density along a flux tube, to 5 or 6, indicating a flux tube with a very low relative density in the equatorial region. We suspect that this index provides an indication of how long a flux tube has been closed. The longer a flux tube is closed the closer its plasma content will get to equilibrium with the ionospheric plasma. Values of m can vary over short distances, suggesting that the spacecraft is moving from one plasma regime to another. We also find that the mean ion mass can vary from just greater than 1 (indicating a nearly pure hydrogen plasma) to about 4 (indicating a high proportion of heavier ions, presumably ionospheric O^+).

We now plan to make use of this technique to map out the various plasma regimes through which CRRES passes on its orbit. This technique should be especially useful to study the complex distribution of plasma regimes seen near dusk, where corotation and convection flows compete producing a stagnation region. Regions of dense plasma separated from the plasmasphere are frequently seen in this vicinity, and on a single orbit CRRES will pass in and out of regions of quite different plasma densities (as deduced from the

plasma wave instrument). Comparing the plasma characteristics of these regions to those of neighboring flux tubes and to the nearby plasmasphere should help us understand their history and origin.

Principal Reference

Hughes, W.J., H.J. Singer, and R.R Anderson, Field aligned plasma distributions derived from ULF field line resonant oscillations, to be submitted to *J. Geophys. Res.*

Other References

Cummings, W.D., R.J. O'Sullivan and P.J. Coleman, Jr., Standing Alfven waves in the magnetosphere, *J. Geophys. Res., 74*, 778, 1969.

VI. Publications

(a) Primary Publications

Basinska, E.M., W.J. Burke, N.C. Maynard, W.J. Hughes, J.D. Winningham, and W.B. Hanson, Small-scale electrodynamics of the cusp with northward IMF, *J. Geophys. Res.* (in press) 1992.

Erickson, G.M., The physics of the Harang discontinuity, 2. Consequences of dawnside depletion, *J. Geophys. Res.* (in press), 1992.

Erickson, G.M., A quasi-static magnetospheric convection model in two dimensions, submitted to *J. Geophys. Res.*

Greenspan, M.E., C.E. Rasmussen, W.J. Burke, and M.A. Abdu, Equatorial density depletions observed at 840 km during the great magnetic storm of March, 1989, *J. Geophys. Res.*, *96*, 13931, 1991.

Paranicas C., W.J. Hughes, H.J. Singer, and R.R. Anderson, Banded electrostatic emissions observed by the CRRES plasma wave experiment, submitted to *J. Geophys. Res.*

(b) Other Publications

Batista, I.S., E.R. de Paula, M.A. Abdu, N.B. Trivedi, and M.E. Greenspan, Ionospheric effects of the March 13, 1989, magnetic storm at low and equatorial latitudes, *J. Geophys. Res.*, *96*, 13943, 1991.

Burke, W.J., E.M. Basinska, N.C. Maynard, W.B. Hanson, J.A. Slavin and J.D. Winningham, Polar cap potentials during periods of positive B_y and northward IMF, submitted to *J. Atmos. Terr. Phys.*

Escoubet, C.P., M.F. Smith, S.F. Fung, P.C. Anderson, R.A. Hoffman, E.M. Basinska, and J.M. Bosqued, Staircase ion signature in the polar cusp: A case study, submitted to *Geophys. Res. Lett.*

Heinemann, M., D.H. Pontius, Jr., and G.M. Erickson, Representation of currents and magnetic fields in steady state isotropic plasma, submitted to *J. Geophys. Res.*

Newell, P.T., W.J. Burke, E.R. Sanchez, C.-I. Meng, M.E. Greenspan and C.R. Clauer, The low latitude boundary layer and the boundary plasma sheet at low altitude: prenoon precipitation regions and convection reversal boundaries, *J. Geophys. Res.* *96*, 21013, 1991.

(c) Papers Presented at Meetings

Baker, K.B., R.A. Greenwald, P.T. Newell, J.R. Dudeney, M. Pinnock, and M.E. Greenspan, HF-radar signatures of the cusp and low-latitude boundary layer, presented at Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS, 72,* 247, 1991).

Basinska, E.M., W.J. Burke, N.C. Maynard, and W.J. Hughes, Hydromagnetic waves near the poleward cusp boundary, presented at Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS, 72,* 249, 1991).

Basinska, E.M., W.J. Burke, N.C. Maynard, W.J. Hughes, Small scale electrodynamics of the cusp during a period of northward IMF, presented at IUGG XX General Assembly, Vienna, August 1991.

Basinska, E.M., W.J. Burke, N.C. Maynard, W.J. Hughes, Potential distributions with northward IMF, presented at the American Geophysical Union Fall Meeting, San Francisco, December 1991 (Abstract: *EOS, 72,* 426, 1991).

Burke, W.J., E.M. Basinska, N.C. Maynard, Persistently high geomagnetic activity during an extended period of northward IMF, presented at IUGG XX General Assembly, Vienna, August 1991.

Burke, W.J., E.M. Basinska, N.C. Maynard, Large polar cap potentials during periods of northward IMF, presented at Dynamics Explorer SWT meeting, GSFC, October 1991.

Erickson, G.M., and M. Heinemann, MHD stability of a finite-width, two-dimensional magnetosphere, presented at Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS, 72,* 243, 1991).

Erickson, G.M., Field aligned currents and the physics of the Harang discontinuity, Invited Paper presented at IUGG XX General Assembly, Vienna, August 1991.

Erickson, G.M., Nightside auroral zone structure, presented at the American Geophysical Union Fall Meeting, San Francisco, December 1991, (Abstract: *EOS, 72,* 415, 1991).

Escoubet, C.P., M.F. Smith, S.F. Fung, R.A. Hoffman, E.M. Basinska, and J.M. Bosqued, Staircase ion signature in the polar cusp: A case study, presented at Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS, 72,* 249, 1991).

Fraser, B.J., H.J. Singer, W.J. Hughes, J.R. Wygant, M. Smiddy, and R.R. Anderson, Initial CRRES observations of electromagnetic ion cyclotron waves at L=3-7, presented at Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS, 72,* 255, 1991).

Fraser, B.J., H.J. Singer, J.R. Wygant, M. Smiddy and R.R. Anderson, Initial CRRES observations of electromagnetic ion cyclotron waves at L=3-7, presented at IUGG XX

General Assembly, Vienna, August 1991.

Fraser, B.J., H.J. Singer, W.J. Hughes, J.R. Wygant, M. Smiddy, and R.R. Anderson, Electromagnetic ion cyclotron wave observations near the plasmapause by the CRRES satellite, presented at the American Geophysical Union Fall Meeting, San Francisco, December 1991, (Abstract: *EOS, 72,* 404, 1991).

Greenspan, M.E., W.J. Burke, F.J. Rich, W.J. Hughes, and R.A. Hellis, DMSP F8 measurements of the topside thermal ion parameters near solar minimum, presented at the American Geophysical Union Fall Meeting, San Francisco, December 1991, (Abstract: *EOS, 72,* 357, 1991).

Hughes, W.J., H.J. Singer, B.J. Fraser, M. Smiddy, and J.R. Wygant, Substorm onsets in the inner magnetosphere: CRRES observations, presented at Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS, 72,* 248, 1991).

Hughes, W.J., H.J. Singer, M. Smiddy and J.R. Wygant, Field line resonant oscillations in magnetic and electric field data: CRRES observations, presented at IUGG XX General Assembly, Vienna, August 1991.

Hughes, W.J., Ionospheric current systems and the magnetic variations they produce: from the equator to subauroral latitudes, Invited Paper presented at IUGG XX General Assembly, Vienna, August 1991.

Hughes, W.J., H.J. Singer, M. Smiddy, J.R. Wygant, and R.R Anderson, Field aligned plasma distributions derived from ULF field line resonant oscillations, presented at the American Geophysical Union Fall Meeting, San Francisco, December 1991, (Abstract: *EOS, 72,* 426, 1991).

Jordan, C.E., J.N. Bass, H.J. Singer, G.R. Ludlow, R.V. Hilmer, K.A. Pfitzer, and A.J. Lazarus, Various magnetic field model representations of the August 26 1990 storm, presented at Spring American Geophysical Union Meeting, Baltimore. May 1991 (Abstract: *EOS, 72,* 238, 1991).

Knudsen, D., E. Basinska, and M.C. Kelly, Localization of Pc1 wave energy near auroral electron precipitation, presented at IUGG XX General Assembly, Vienna, August 1991.

Ludlow, G.R., W.J. Hughes, C. Paranicas, H.J. Singer, M.S. Gussenhoven, and R.W. Nightingale, CRRES observations of ULF waves during magnetic storm of August 26, 1990, presented at Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS, 72,* 238, 1991).

Ludlow, G.R., W.J. Hughes, C. Paranicas, H.J. Singer, M.S. Gussenhoven and M. Violet, ULF waves excited by SSC's: CRRES magnetometer observations, presented at the American Geophysical Union Fall Meeting, San Francisco, December 1991, (Abstract: *EOS, 72,* 394, 1991).

Newell, P.T., E.R. Sanchez, C.-I. Meng, M.E. Greenspan, W.J. Burke, and C.R. Clauer, Distinguishing the LLBL and the BPS at low altitude: dayside precipitation regions and convection reversal boundaries, presented at Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS, 72,* 234, 1991).

Paranicas, C.P., W.J. Hughes, H.J. Singer, and R.R. Anderson, Structure of banded electrostatic emissions observed by the CRRES satellite, presented at Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS, 72,* 259, 1991).

Paranicas, C.P., W.J. Hughes, H.J. Singer and R.R. Anderson, Structure of electrostatic emissions observed by the CRRES satellite, presented at IUGG XX General Assembly, Vienna, August 1991.

Paranicas, C., W.J. Hughes, H.J. Singer, R.R. Anderson, and D. Hardy, Interaction of banded electrostatic emissions and energetic electrons as observed by CRRES, presented at the American Geophysical Union Fall Meeting, San Francisco, December 1991, (Abstract: *EOS, 72,* 398, 1991).

Singer, H.J., W.J. Hughes, R. Anderson, J. Wygant, W. McNeil, and D.L. Reasoner, Diamagnetic cavities formed by the CRRES high altitude chemical release experiments, presented at Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS, 72,* 230, 1991).

Singer, H.J., W.J. Hughes, R. Anderson, J. Wygant, W. McNeil and D.L. Reasoner, Diamagnetic cavities formed by the CRRES high altitude chemical release experiments, presented at IUGG XX General Assembly, Vienna, August 1991.

Singer, H.J., W.J. Hughes, J. Wygant, R.R. Anderson, ULF waves observed during CRRES high altitude chemical release experiments, presented at the American Geophysical Union Fall Meeting, San Francisco, December 1991, (Abstract: *EOS, 72,* 394, 1991).

Violet, M.D., M.S. Gussenhoven, H.J. Singer, D.H. Brautigam, D.A. Hardy, K.J. Kerns, R.R. Anderson, C.E. Jordan, G.R. Ludlow, A. Vampola, and A. Korth, Magnetospheric response to the 26 August 1990 sudden commencement, presented at Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS, 72,* 233, 1991).